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Sandia National Laboratories

Focused Ion Beam Implantation from eV to MeV Energies

Michael Titze

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U.S. DEPARTMENT OF ENERGY
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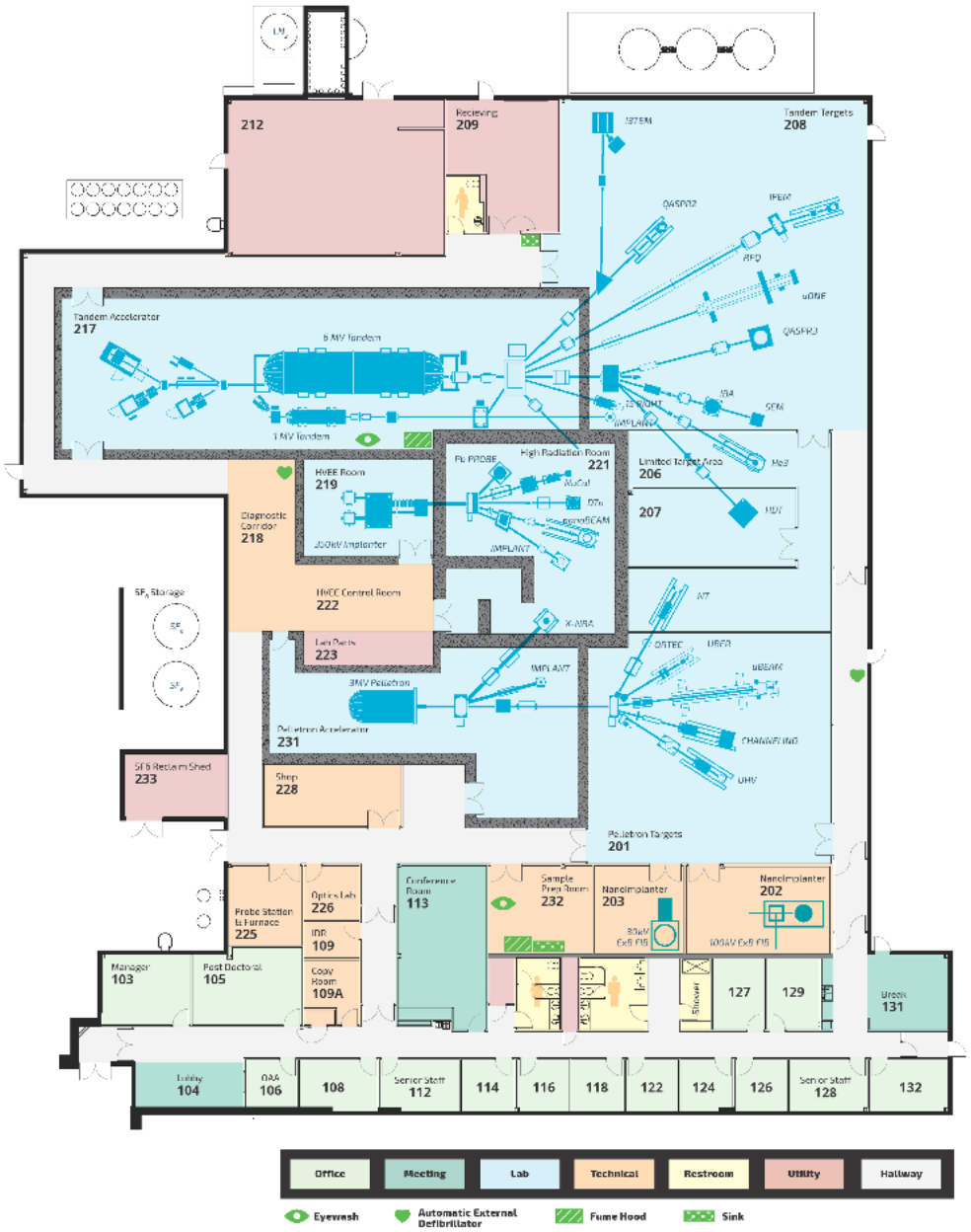
building 720
ION BEAM LABORATORY

Sandia's Ion Beam Laboratory (IBL)



7 Operational Accelerators and >25 end-stations

(including *in-situ* DLTS, PL, TEM, SEM, 1200°C heating, etc...)

Operational

(1) 6 MV Tandem Accelerator

(2) 3 MV Pelletron Accelerator

(3) 1 MV Tandem Accelerator

(4) 350 kV HVEE Implanter

High energy focused microbeams 1 μm

(5) 100 kV ExB FIB nanoImplanter

(6) 35 kV ExB FIB Raith Velion

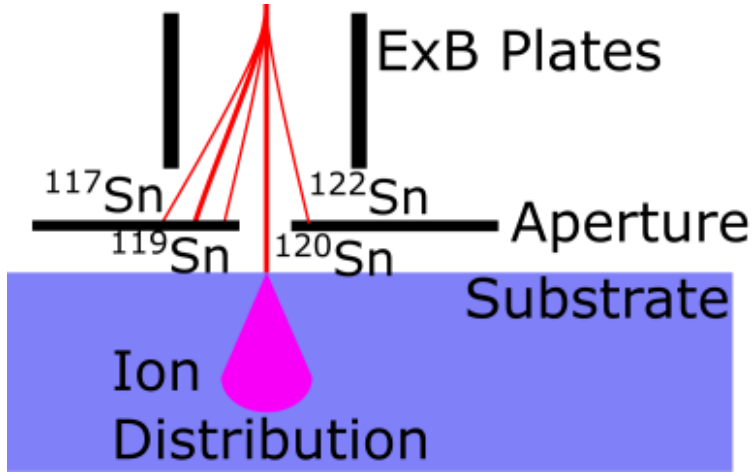
(7) 35 kV Zeiss HeIM

Low energy focused nanobeams <1 to 20 nm

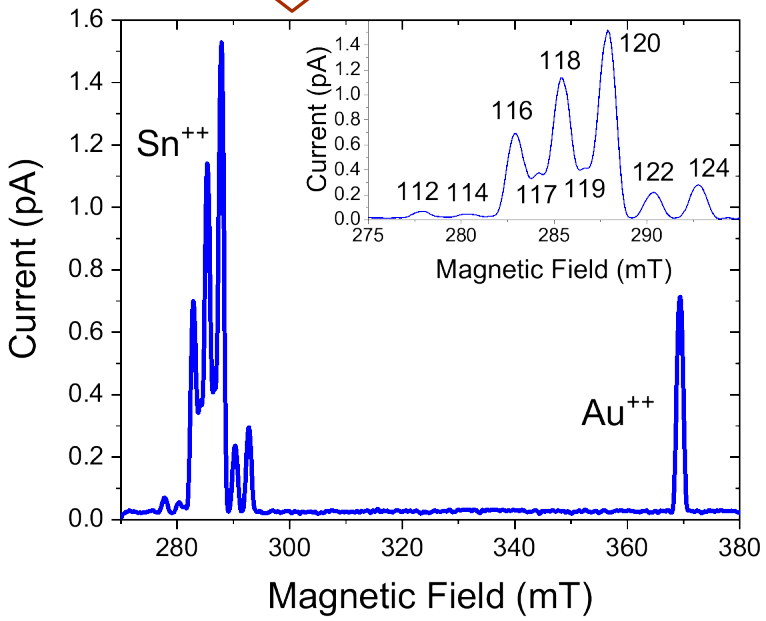
Installing

(8) 35 kV Plasma FIB

Liquid Metal Alloy Ion Sources – Available Ions



E / B Field Scan



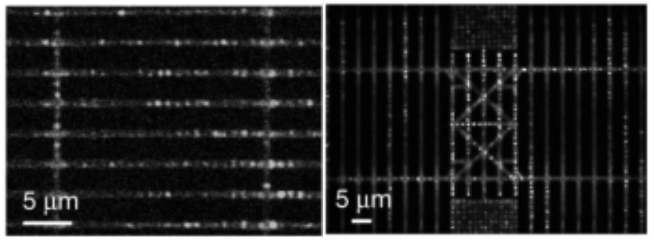
Adapted from L. Bischoff et al., Appl. Phys. Rev., 3 (2016)

Green: Demonstrated at SNL
Purple: Attempting at SNL
Yellow: Demonstrated at other lab

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og
			58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	
									98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr			

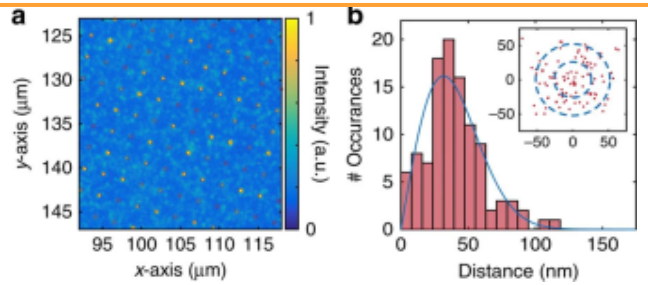
Added 8 new elements over past 3 years

Scalable Implantation



N. Wan et al., Nature, 583, 226 (2020)

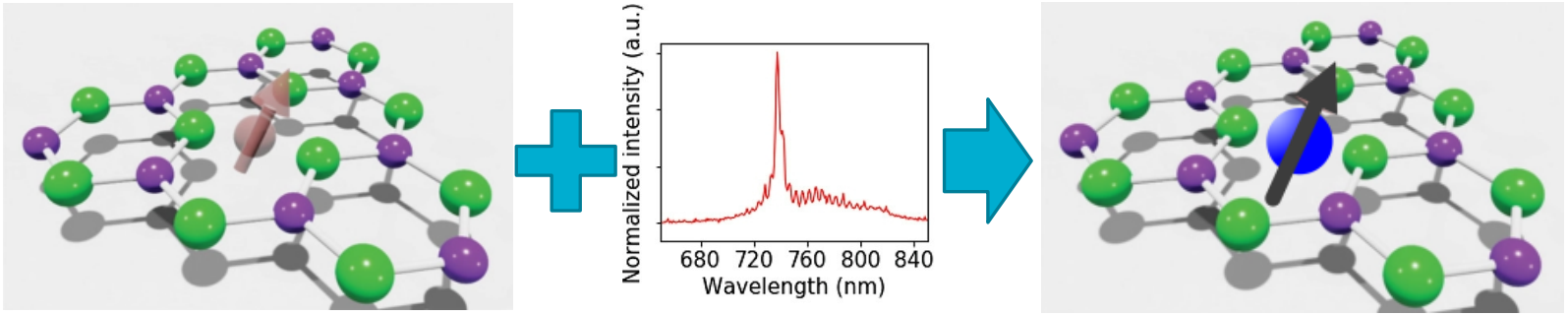
< 50 nm Targeting Resolution



T. Schroder et al., Nat. Communs., 8, 15376 (2017)

Low Energy Implantation - Motivation

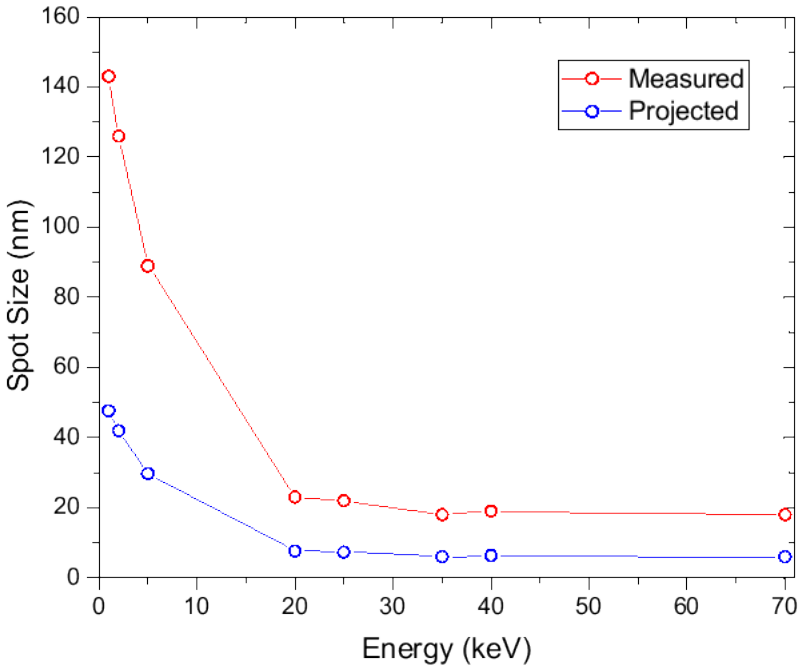
- 2D materials are attractive material class for CMOS-integrable quantum optics
- Deterministic placement of **impurity**-type emitters is challenging
  - Stopping in single atomic layer
  - Minimize damage to surrounding lattice
  - Introduce non-native atom



N. Mendelson et al., Adv. Mater., 34, 2106046 (2022)

M. Titze et al., Nano Lett. (2022)

At low energy chromatic abberations become more prominent



Range Measurements towards Ultra-Low Energy Implantation

- Indicates that 100s of eV will be sufficient to target single atomic layers
  - Can do (at cost of spot size) with ~15 eV energy spread